

# Multilevel MaxEnt grammars for probabilistic morphologically-conditioned tonotactics

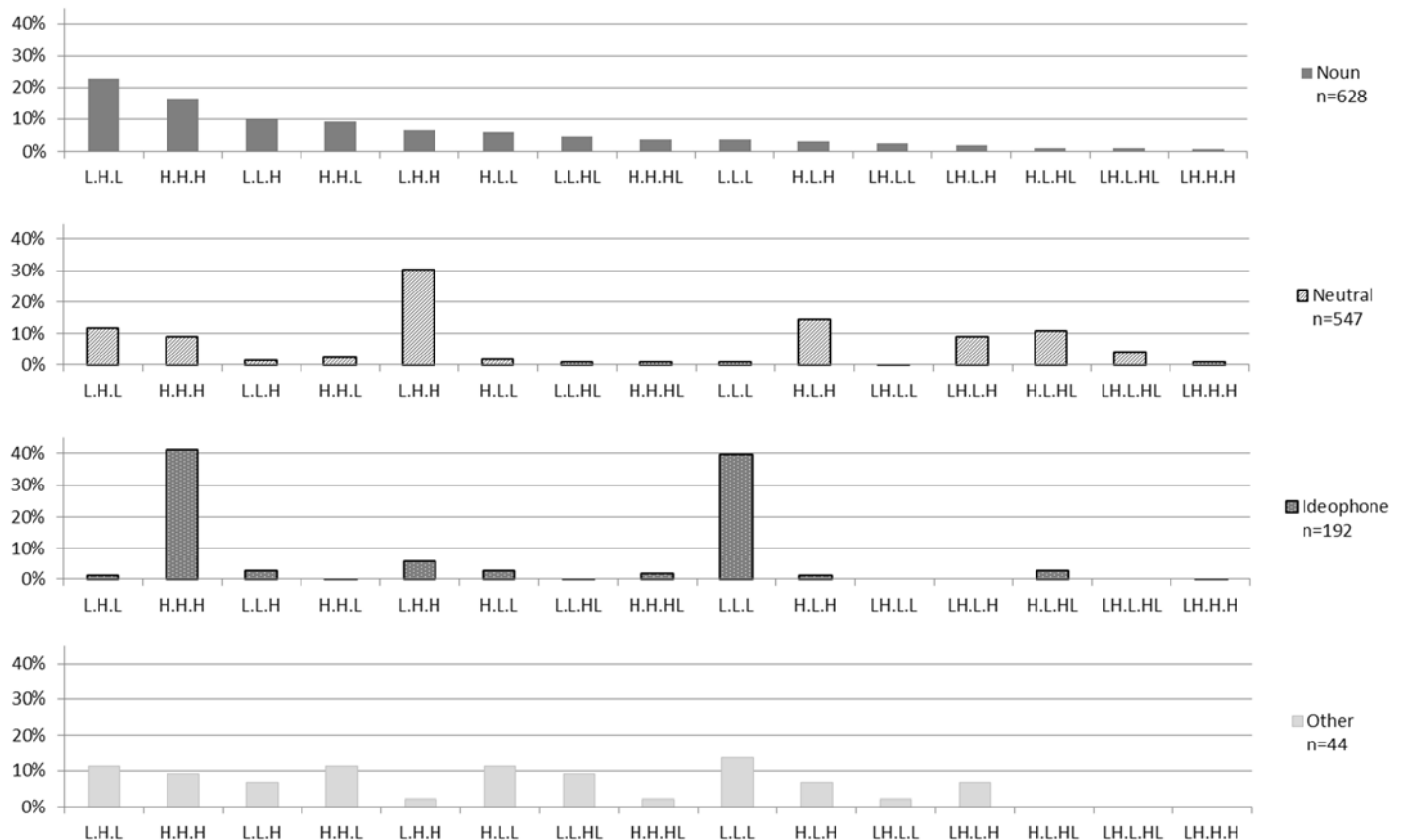
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## 1 INTRODUCTION

❖ This talk presents a case of lexically-conditioned tonotactics variation from Mende (Mande, Sierra Leone).

(1) Top trisyllabic surface tone patterns in the Mende lexicon



- Part of speech-sensitive patterns =
  - different lexical classes can exhibit different phonological patterns.
  - noted cross-linguistically: e.g., English noun versus verb stress patterns
  - applications in e.g., comprehension, parsing
- Two hypotheses about how lexical class-conditioned sensitivity could work:
  - A. Lexical class differences are limited by the grammar/UG.
    - differences only in faithfulness, not markedness (e.g., Ito & Mester 1995; Alderete 2001; Smith 2011)
    - preferential classes, e.g., nouns // verbs will show a subset of noun patterns (e.g., Smith 2011)
  - B. Lexical classes can each have their own completely independent phonological profiles (e.g., Ito & Mester 1995; Inkelas & Zoll 2007; Anttila 2002; Pater 2009).
    - ↳ We argue for this latter hypothesis here.

- ❖ This talk:
  - quantitatively models space of lexically-conditioned variation and frequency of variation across the corpus,
  - using a ‘varying slopes’ approach in Maximum Entropy Harmonic Grammar (MaxEnt; Goldwater & Johnson 2003; Wilson 2006; Jäger 2007; Hayes & Wilson 2008; a.o.).
  - ↳ This approach directly addresses the overarching problem in morphophonology of how to quantify the heterogeneity that morphological conditioning can engender in a phonological system.

## 2 MENDE TONOTACTICS

### 2.1 History, early generative accounts

- Early generative accounts of Mende noticed common tone patterns recurrent in the language, particularly in nouns (Leben 1978) → ‘tone melodies’ (see also Hyman 1987 for similar tone melodies in Kukuya),
- In Autosegmental Phonology, these surface tone patterns were modeled using
  - geometric association conventions of Autosegmental Phonology
  - 5 underlying tone melodies (H, L, HL, LH, LHL) as source of all surface patterns.

- (2) ndàvùlá ‘sling’  $L \rightarrow R, 1 \leftrightarrow 1$  association, then spread.
- $\begin{array}{c} | \quad \vee \\ L \quad H \end{array}$

- But, subsequent work pointed out many surface patterns that deviate from the supposed five melodies or their “universal” autosegmental association principles (Dwyer 1978; Conteh et al. 1983; Zoll 2003; Zhang 2007).

- (3) a. lèlémá ‘praying mantis’ *violates association principles*
- $\begin{array}{c} \vee \quad | \\ L \quad H \end{array}$
- b. gbágběmà ‘sensitive plant’ *cannot arise from one of the 5 tone melodies; violates association principles*
- $\begin{array}{c} | \quad \wedge \quad | \\ H \quad LH \quad L \end{array}$

### 2.2 Data

- Mende dictionary:  $n=5,412$  (Innes 1969)
- 1 to 3-syllable words:  $n=4,989$ 
  - Morpheme breaks are not indicated in Innes, but a primary source of morphological complexity (in nouns, at least) appears to be total reduplication in 4-syllable words, which we’re not looking at here.
- Parts of speech
  - Nouns 2,494
  - Neutrals 1,442 (verbs, adjectives)
  - Ideophones 762
  - Other 291 (pronouns, conjunctions, interjections, adverbs, etc.)

### 2.3 A fresh look at tone: the theoretical underpinnings

- Agreement by Correspondence Theory (ABC; Hansson 2001; Rose & Walker 2004; Bennett 2013; a.o.)
  - grounded in basic principles of similarity and proximity attraction, modeling instability in syntagmatic phonological relationships (Wayment 2009; Inkelas & Shih 2013).
  - Elements that are sufficiently similar/proximal interact in e.g., assimilation/dissimilation.
  - For simplicity in this talk, constraints are reformulated into more familiar phonotactic markedness format (but it’s still ABC under the hood; cf. Hansson 2014).
- Q Theory (e.g., Shih & Inkelas 2014)
  - decomposes segments into strings of (2 or 3) smaller, temporally-sequenced, featurally-uniform subsegments, which bear tone features.

- (4)
- a.  $Q \rightarrow (q^1 \ q^2)$
  - b.  $\tilde{a} \rightarrow (\tilde{a} \ \tilde{a})$
  - c.  $\widehat{LH} \rightarrow (L \ H)$

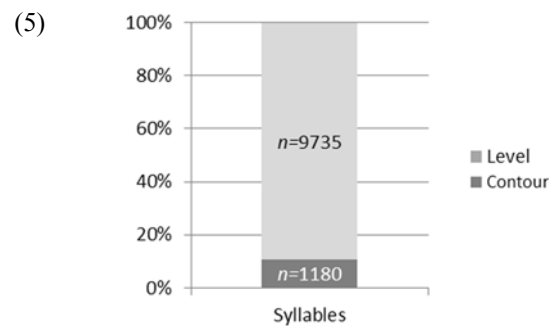
- provides a more fine-grained point of reference for the grammar: crucial for e.g., contour tones.
- divorces issue of what are the minimal units that carry tone features versus what are the units that participate in tonal alternations/phenomena.

- Basic relevant differences between Autosegmentalism (e.g., Leben 1973) and ABC+Q for this talk:
  - Constraints grounded in principles of similarity- and proximity-based interaction.
  - No reliance on geometric, autosegmental ‘line’ representations
  - No reliance on operations that reference autosegmental ‘lines’: i.e., tone association rules.<sup>1</sup>

## 2.4 Observed patterns for Mende surface tones

- Primary observations taken from Inkelas & Shih 2015.

### 2.4.1 Contour toned syllables (and tone transitions in general—except at syllable boundaries) are avoided.



- Significantly fewer contour syllables than expected, if syllable tone patterns could be HH, LL, LH, and HL.  $\chi^2=6705.270, p<0.0001$ .

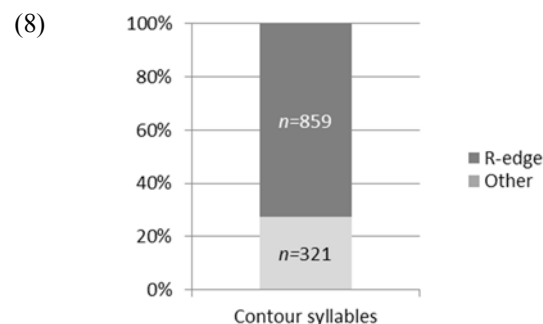
- (6)  $*[\alpha T]::[\beta T]$  (\*CHANGE)

Penalise every sequence of adjacent  $q$ 's that are tonally non-identical.

(7)

$\sigma.\sigma$	$freq$	*CHANGE $*[\alpha T]::[\beta T]$
a. HH.HH	995	
b. LL.HH	701	W1
c. LL.HL	389	W2

### 2.4.2 If necessary, contour tones are tolerated at the right edge.



- The significant majority of contour syllables occur at the right edge of words.
- versus equal probability across all syllables:  $\chi^2=353.407, p<0.0001$ .

<sup>1</sup> This possibility was hinted at by Zoll (2003), but not fully explored.

- (9)  $*([\alpha T]::[\beta T])_{\sigma W}$  (\*WeakCONTOUR) Penalise every adjacent  $q$  sequence of non-identical tones within a weak (i.e., non-final) syllable. (cf. COINCIDE-CONTOUR; Zoll 2003)

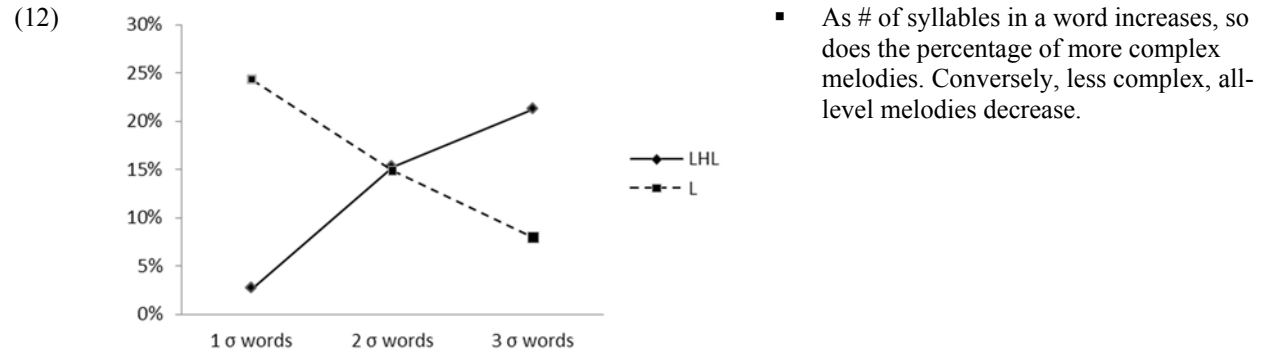
(10)

$\sigma.\sigma$	$freq$	*WeakCONTOUR $*([\alpha T]::[\beta T])_{\sigma W}$	*CHANGE $*[\alpha T]::[\beta T]$
a. LL.HL	389		2
b. LH.LL	77	W1	2

### 2.4.3 Tone changes align with syllable boundaries

- (11)  ■ Level tone  
■ Tone changes
- Syllable boundaries coincide significantly with tone changes (in polysyllabic words that have non-level surface patterns) .  $\chi^2=1428.074$ ,  $p<0.0001$

- Resulting prediction: tone melody complexity should correlate with the number of syllables in a word. More syllables  $\rightarrow$  more non-level tone patterns (Inkelas & Shih 2015).

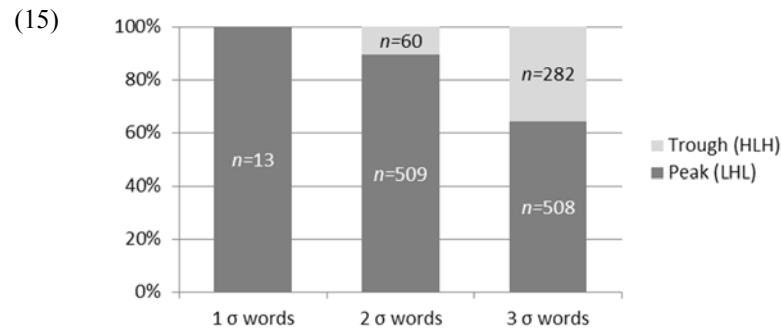


- (13)  $*[\alpha T]:\$:[\alpha T]$  (CHANGE@\\$) Penalise every adjacent, tonally-identical  $q$  sequence that is separated by a syllable boundary (\$). (cf. xx-Edge constraints; Bennett 2013)

(14)

$\sigma.\sigma.\sigma$	$freq$	CHANGE@\\$ $*[\alpha T]:\$:[\alpha T]$	*WeakCONTOUR $*([\alpha T]::[\beta T])_{\sigma W}$	*CHANGE $*[\alpha T]::[\beta T]$
a. LL.HH.LL	233			2
b. LL.HH.HH	218	W1		L1
c. LL.LL.LL	112	W2		L
d. LL.LL.HH	78	W1		L1
e. LH.LL.HH	64		W1	W3
f. LH.HH.LL	7	W1	W1	2

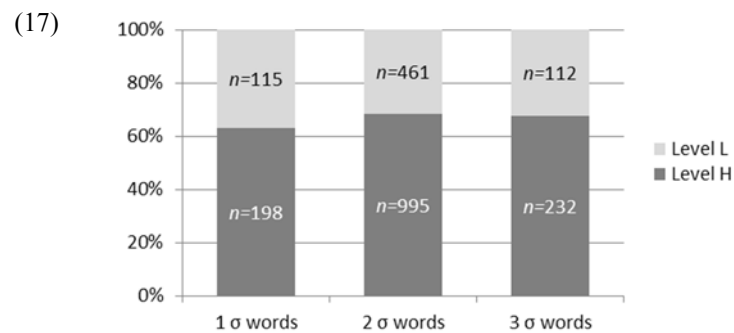
#### 2.4.4 HLH troughs are avoided



- Troughs are underrepresented, but their presence increases as the number of syllables in words increases.

- (16) \*TROUGH Penalise any two H tones separated by any number of consecutive L tones. (Cahill 2007; a.o.)

#### 2.4.5 Words preferably have at least one H tone



- Level H tone patterns (e.g., HH.HH.HH) are more common than Level L tone patterns (e.g., LL.LL.LL).

- (18) HAVEH Penalise any word with no H tone.

### 2.5 Constraint summary

(19)

Constraint	Nickname	Definition
*[αT]::[βT]	*CHANGE	Penalise every sequence of adjacent <i>q</i> 's that are tonally non-identical.
*([αT]::[βT]) <sub>σw</sub>	*WeakCONTOUR	Penalise every adjacent <i>q</i> sequence of non-identical tones within a weak (i.e., non-final) syllable.
*[αT]:\$:[αT]	CHANGE@\$	Penalise every adjacent, identical <i>q</i> sequence that is separated by a syllable boundary.
*TROUGH	*TROUGH	Penalise any two H tones separated by any number of consecutive L tones.
HAVEH	HAVEH	Penalise any word with no H tone.

- Caveat: as of now, we don't have anything to say about the alignment of LH and HL melodies over trisyllabic words (e.g., L.H.H versus L.L.H; H.L.L versus H.H.L), so our model will be underdetermined for this portion of the data (for more discussion, see e.g., Inkelas & Shih 2015).
- Note that no matter the OT analysis, the goal in this paper is to examine and model the variance of part-of-speech-specific tonotactics. (Almost) any constraint set would be fine for this, and the fact that there's lexically-conditioned differences (see (1)) doesn't change.

### 3 ANALYSIS

#### 3.1 Maximum Entropy Harmonic Grammar

- Maximum Entropy Harmonic Grammar (MaxEnt) (Goldwater & Johnson 2003; Wilson 2006; Jäger 2007; Hayes & Wilson 2008; a.o.), fitted using MaxEnt Grammar Tool (Hayes et al. 2009).<sup>2</sup>
  - ranks probabilities (i.e., comparative grammaticality) of outcome candidates in variable data.
- Output = probability distribution over all possible surface tone pattern combinations of LL, HH, LH, HL syllables (LHL, HLH are found on monosyllables only)

#### 3.2 Cophonologies/Indexed Constraints as Varying Slopes

- Morphologically-conditioned phonology can be modeled via indexed constraints (e.g., Ito & Mester 1999; Alderete 2001; Smith 2001) or as cophonologies (e.g., Anttila 2002; Inkelas & Zoll 2005).
- Varying slopes = additive weight adjustment for constraints in the Base Grammar, per each lexical class.
  - Such an approach has been hinted at before: e.g., Albright 2008; Coetzee & Pater 2011; Moore-Cantwell & Pater, submitted.

$$(20) \quad w_1 C_1 + w_2 (C_1 \times \text{NOUN}) + w_3 (C_1 \times \text{NEUT}) + w_4 (C_1 \times \text{ID}) + \dots + w_k C_{iN} \quad (\text{cf. fn 2})$$

Base grammar	=	$w_1 C_1$
Adjusted noun grammar	=	$w_1 C_1 + w_2 (C_1 \times \text{NOUN})$
Adjusted neutral grammar	=	$w_1 C_1 + w_3 (C_1 \times \text{NEUT})$
Adjusted ideophone grammar	=	$w_1 C_1 + w_4 (C_1 \times \text{ID})$

- Base Grammar predicts overall tonotactics for the language, and lexical class-specific tonotactics are predicted by the additive combination of weights of Base Grammar constraints and class-specific weights.
- Cophonologies  $\cong$  bundles of Indexed Constraints.
- Because there is a finite set of lexical classes, varying slopes are formally executed here as interaction terms.<sup>3</sup>
  - for other previous uses of interaction terms in MaxEnt HG, usually as weighted constraint conjunction: see e.g., Hayes et al. 2012; Pater & Moreton 2012; Green & Davis 2014; Shih, to appear.

#### 3.3 What is the base grammar?

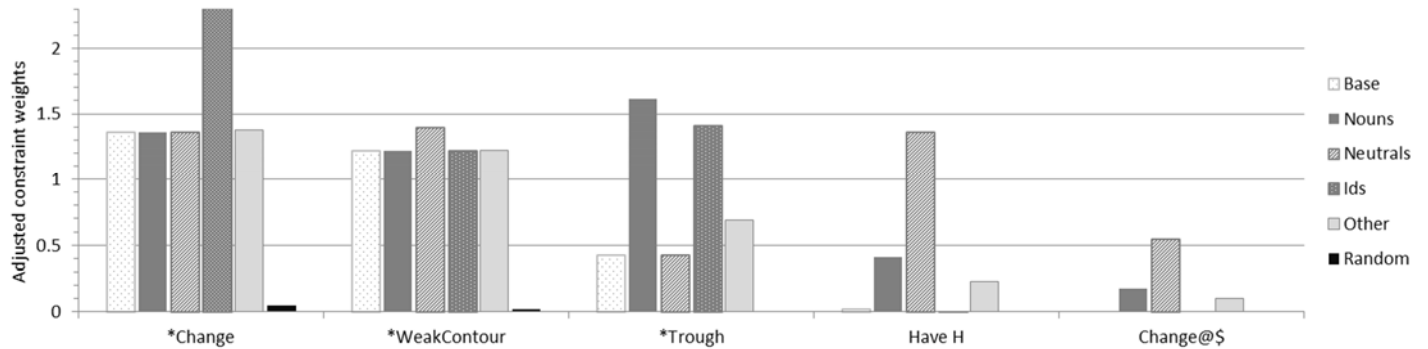
- Trained a base grammar on bootstrapped samples ( $n=2500$  / sample) of possible tone melodies in Mende, drawn from the existing distribution.
  - mirrors a Mende speaker knowing word tone patterns but not (yet) part of speech.
  - did not want to *a priori* assume one lexical class as “default.”
  - across base grammar samples, the results are stable; a representative result is reported here.
- A grammar trained without any data for base grammar provides very similar results (not reported here).
- Another baseline: grammar on a totally random tone patterns ( $n=5000$ ), generated from random combinations of HH, LL, LH, and HL syllables for 1–3 syllable words is also provided here for comparison.

<sup>2</sup>  $\mathcal{H}armony(x, i) = \sum_{k=1}^N w_k C_i(x) = \mathbf{w}_k \cdot \mathbf{C}_i$ ; where  $x$  = candidate for input  $i$ ,  $w_k$  = weight of constraint  $C_i$ ,  $C_i(x)$  = number of violations of  $C_i$  that  $x$  incurs, and  $N$  = vector of constraints ( $C_{i1} \dots C_{iN}$ ).

<sup>3</sup> For justification on the equivalency of interaction terms and random slopes in this situation, see e.g., Gelman & Hill 2007.

## 4 RESULTS

- (21) Adjusted MaxEnt weights, in graphical form  
(adjusted  $wC_i = \text{base } wC_i + \text{indexed } wC_i$ )



- (22) Adjusted MaxEnt weights, in numbers

	Base	Adjusted Grammars				Random
		<i>Nouns</i>	<i>Neutrals</i>	<i>Ideophones</i>	<i>Other</i>	
*CHANGE	1.356	1.356	1.356	2.537	1.374	0.047
*WeakCONTOUR	1.220	1.220	1.391	1.220	1.220	0.018
*TROUGH	0.426	1.612	0.426	1.409	0.691	0
HAVE H	0.017	0.411	1.361	0.017	0.232	0
CHANGE@\$	0	0.175	0.543	0	0.099	0

- (23) Constraint weights by lexical class (top→bottom: highest weight→lowest weight)

Base	Cophonology Indexed Grammars			
	<i>Nouns</i>	<i>Neutrals</i>	<i>Ideophones</i>	<i>Other</i>
*CHANGE	*TROUGH	*WeakCONTOUR	*CHANGE	*CHANGE
*WeakCONTOUR	*CHANGE	HAVE H	*TROUGH	*WeakCONTOUR
*TROUGH	*WeakCONTOUR	*CHANGE	*WeakCONTOUR	*TROUGH
HAVE H	HAVE H	CHANGE@\$	CHANGE@\$	HAVE H
CHANGE@\$	CHANGE@\$	*TROUGH	HAVE H	CHANGE@\$

### 4.1 Results and observations

#### 4.1.1 Sanity check

- A MaxEnt grammar on completely random data yields constraint weights pretty close to 0.

#### 4.1.2 Base grammar

- Reveals importance of general contour tone avoidance and R-edge contour tone alignment.
  - \*CHANGE = 1.356
  - \*WeakCONTOUR = 1.220
  - cf. “Random” model results, where weights are much lower, nearly at 0.
- These two constraints remain highly weighted across all lexical classes.
  - weight of \*WeakCONTOUR stays stable across the lexicon, suggesting that it’s a very general principle.
- Reflects universal dispreferences for (nonfinal) contour tones (e.g., Gordon 2001; Zhang 2004).

## 4.1.3 Syllable edge – Tone change alignment

- Only nouns and neutrals show an effect of syllable edge-tone transition alignment. → see adjusted weights for CHANGE@\$:
  - CHANGE@\$×NOUN = 0.175, CHANGE@\$×NEUT = 0.543
  - versus CHANGE@\$×ID = 0
- Shows that ideophones often involve much simpler surface tone patterns than the other lexical classes.
  - e.g., *vòvòlò* ‘creaking’
  - In addition, ideophones significantly increase the weight of \*CHANGE

(24)

$\sigma.\sigma.\sigma$ , ID	<i>freq</i>	*CHANGE×ID *[ $\alpha$ T]:[ $\beta$ T]×ID $w_{adj}=2.537$	CHANGE@\$×ID *[ $\alpha$ T]:\$:[ $\alpha$ T]×ID $w_{adj}=0$	$\mathcal{H}$
a. LL.HH.LL	2	W2		<b>5.073</b>
☞ b. LL.LL.LL	76		L2	<b>0</b>

## 4.1.4 HAVE H: a verb thing

- Neutrals in particular (but also nouns to a certain extent) show a much greater affinity for a requisite H tone than ideophones.
  - = level L surface patterns much more tolerated for Ideophones > Nouns > Neutrals.

(25)

$\sigma.\sigma.\sigma$ , NEUT	<i>freq</i>	HAVEH×NEUT $w_{adj}=1.360656$	$\mathcal{H}$
a. LL.LL.LL	5	1	<b>1.36</b>

$\sigma.\sigma.\sigma$ , NOUN		HAVEH×NOUN $w_{adj}=0.410611$	
b. LL.LL.LL	25	1	<b>0.41</b>

$\sigma.\sigma.\sigma$ , ID		HAVEH×ID $w_{adj}=0.016843$	
c. LL.LL.LL	76	1	<b>.02</b>

## 4.1.5 \*TROUGH: not a verb thing

- Neutrals also differ from Nouns and Ideophones by showing greater preference for tone transitions that align with syllable boundaries, even if these result in a HLH trough.
  - e.g., *húvùndí* ‘be mouldy, mildewed’
  - Much lower adjusted weight for \*TROUGH in Neutrals than other lexical classes:
  - \*TROUGH×NEUT = 0.426, \*TROUGH×NOUN = 1.612, \*TROUGH×ID = 1.409

(26)

	$\sigma.\sigma.\sigma$ , NEUT	<i>freq</i>	*TROUGH×NEUT $w_{adj}=0.426$	CHANGE@\$ *[ $\alpha$ T]:\$:[ $\alpha$ T]×NEUT $w_{adj}=0.543$	$\mathcal{H}$
a.	☞ i. HH.LL.HH	78	1		<b>0.43</b>
	ii. HH.HH.HH	48		<b>2</b>	<b>1.09</b>

	$\sigma.\sigma.\sigma$ , NOUN		*TROUGH×NOUN $w_{adj}=1.612$	*[ $\alpha$ T]:\$:[ $\alpha$ T]×NOUN $w_{adj}=0.175$	
b.	i. HH.LL.HH	21	1		<b>1.61</b>
	☞ ii. HH.HH.HH	101		<b>2</b>	<b>0.35</b>

	$\sigma.\sigma.\sigma$ , ID		*TROUGH×ID $w_{adj}=1.409$	*[ $\alpha$ T]:\$:[ $\alpha$ T]×ID $w_{adj}=0$	
c.	i. HH.LL.HH	2	1		<b>1.41</b>
	☞ ii. HH.HH.HH	79		<b>2</b>	<b>0.00</b>



#### 4.1.6 Correlation of surface tone pattern and lexical class

- How much utility do surface tone patterns have for predicting the lexical class of a word?
- Given a particular trisyllabic tone pattern, which lexical class is it most likely a member of?
  - Predicted results are largely congruent with observations, for level and more complex melodies:

(27)

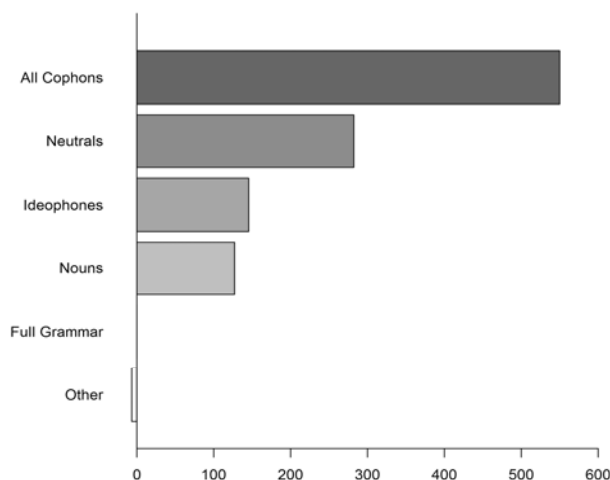
Surface tone	Observed class	Predicted class	Correct prediction?
HH.HH.HH	Id	Id	✓
LL.LL.LL	Id	Id	✓
HH.LL.HH	Neut	Neut	✓
LL.HH.LL	Noun	Neut	*

- Misprediction of LL.HH.LL due to the fact that our system cannot yet privilege H's from L's (and hence no special privilege of multiple H's or L's).

## 4.2 Importance of lexical conditioning

- Are the cophology/indexed grammars contributing significantly to improving our base grammar?
- Tested here using Akaike Information Criterion ( $AIC_C$ ) model comparison.<sup>4</sup>
  - How much information is lost when cophology/indexed constraints are removed?

- (28)  $\Delta AIC_C$  from full model for each cophology removed  
 = how much information is lost for each cophology is in turn removed.<sup>5</sup>



- $AIC_C$  comparison results show that lexical class-specific cophologies/indexed constraints produce a better fit for the data.
  - Exception that is expected: the “Other” part of speech class, which is heterogeneous as is.
- Certain lexical classes provide more information on top of the baseline, suggesting ‘distance’ from the full model.
  - Neutral-specific cophology contributes a lot of additional information to the grammar.
  - Interestingly, ideophones are *not* the most extreme lexical class.
- For future work: comparing individual indexed constraints versus entire cophologies of indexed constraints.

<sup>4</sup> Second-order  $AIC_C$  is used here, because it adjusts more strictly for differences in the number of constraints between comparison grammars. See e.g., Burnham & Anderson 2002 for justification of  $AIC_C$ -based model comparison. For use in comparing phonological grammars, see e.g., Shih, to appear (cf. Wilson & Obdeyn 2009).

<sup>5</sup>  $\Delta AIC_C \geq 10$  is considered large (equivalent to 150:1 that the second best model has essentially no support of being as good as the best model).

## 5 IMPLICATIONS & CONCLUSION

### Lexically-conditioned phonology

- Part-of-speech phonological differences go beyond noun-adjective-verb distinctions (as observed by e.g., Smith 2011).
  - ↳ more closely resemble the complexity of morphophonological alternations and variation.
- Lexically-conditioned phonology is not just a matter of differential faithfulness (e.g., FAITH<sub>NOUN</sub> » FAITH<sub>VERB</sub>; Smith 2001, 2011).
  - Though there is undoubtedly a role for faithfulness, we haven't yet incorporated it into the current system.
- Overall, indexation of markedness constraints per lexical class gains better fit for the data.
- There are hints of markedness reversals of the kind that 'Grammar Dependence' (Alderete 2001) predicts impossible (cf. Pater 2009):
  - E.g., Across nearly all of the grammars (base and lexical class-specific) in Mende, \*TROUGH is ranked fairly highly w/r/t the other constraints.
  - In Neutrals, however, \*TROUGH is weighted at the bottom.
  - ↳ Therefore, a structure (e.g., HLH) that might otherwise be highly marked in the rest of the language is quite good and (comparatively) unmarked for Neutrals.

### Quantifying morphological conditioning

- Our approach can quantify how much lexical class-specific phonotactics can differ from the rest of the lexicon.
  - E.g., how different can ideophone phonology be? → long standing issue for e.g., African languages (see Rose 2015 for recent summary).
  - Results show that ideophones operate within fairly conservative parameters of the overall Mende tonotactics grammar—cf., neutrals.
  - Potentially useful as a scale of ideophone idiosyncrasy (cf. Newman 2001 on Hausa ideophones).
- Because we *a priori* restrict standard HG/OT grammars to positive weights (i.e., to only penalise rather than reward structures), we're not really examining the full potential space of variation between cophonologies yet.
- In the future, this 'varying slopes' approach could extend to other types of morphology (e.g., affixation; dominant tone melodies): e.g., what are the tone patterns that are grammaticalised in a language as productive morphemes?

### For the future

- What is the utility of these phonological differences between groups?
  - There's evidence from other languages that speakers are capable of learning these lexical statistics (e.g., Coetzee 2014),
  - and that such phonological differences help in e.g., acquisition, processing, information load (e.g., Monaghan et al. 2010).

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*To save trees, references are available online.*

[http://cogsci.ucmerced.edu/shih/ShihInkelas\\_LSA2016handout.pdf](http://cogsci.ucmerced.edu/shih/ShihInkelas_LSA2016handout.pdf)

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